SunShot Systems Integration: Enabling Ubiquitous Solar

energy.gov/sunshot

10/22/2015

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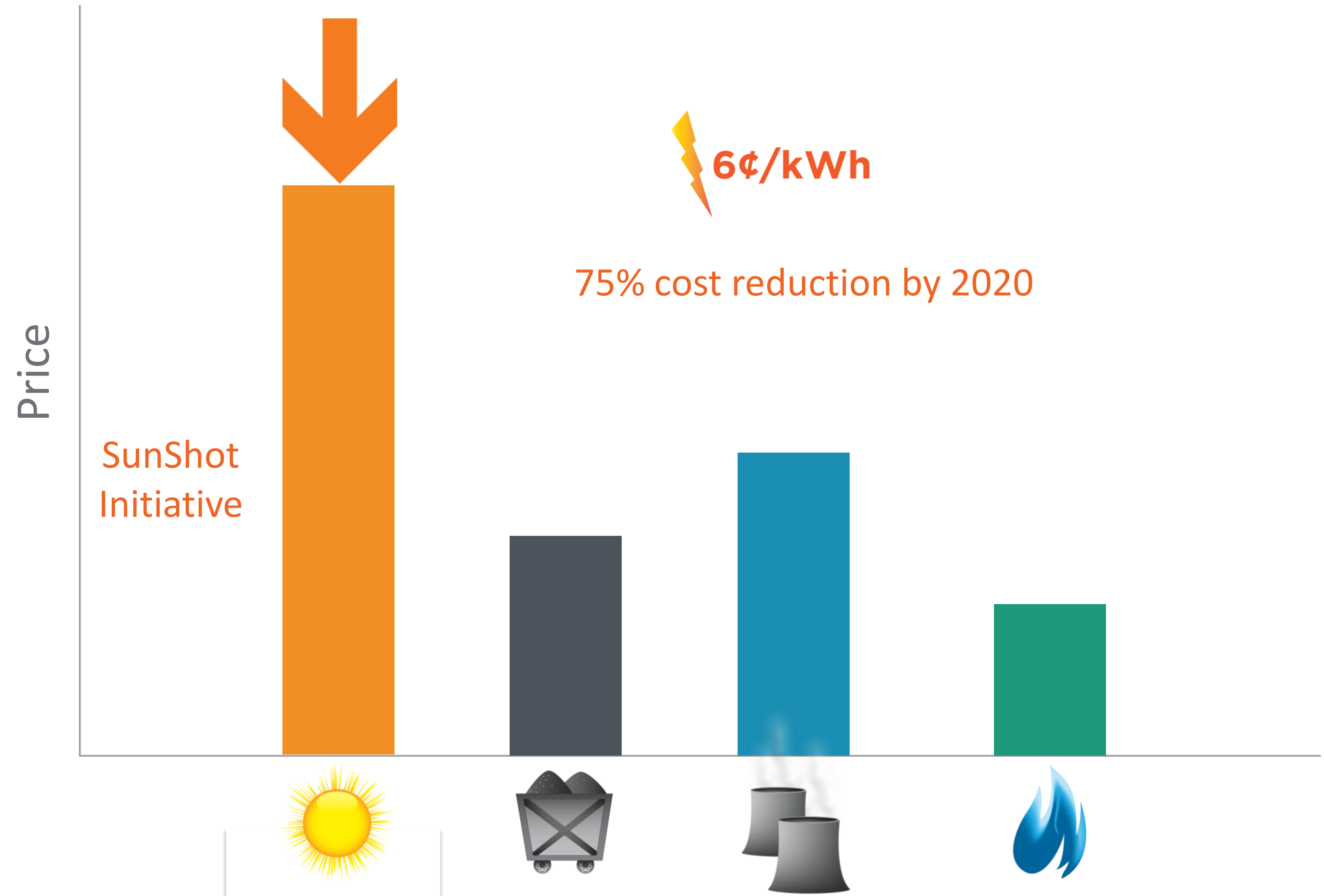
SunShot Goal



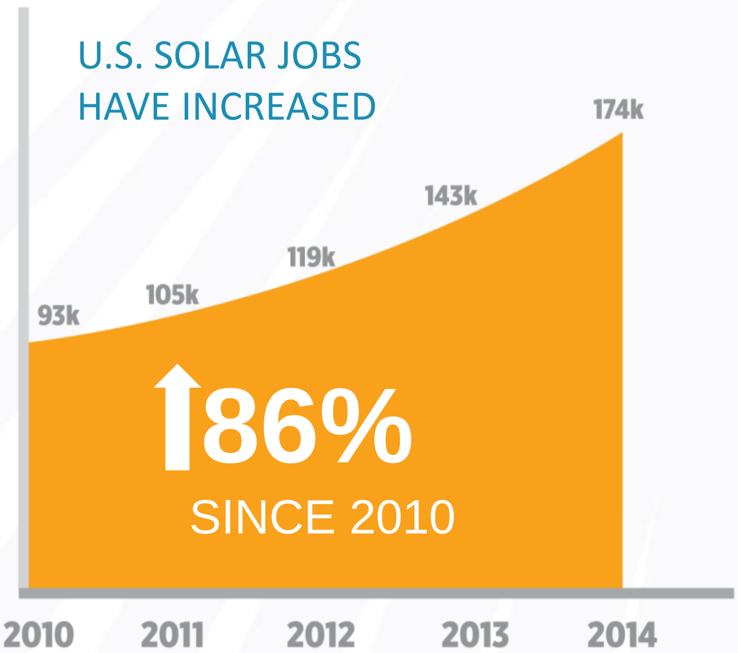
SunShot: Growing Capacity & Economic Impact

At the end of **2014…**

20 GW

Enough to power
4,000,000
average American homes

Solar accounted for
32% of all new electrical
generation capacity installed in 2014.

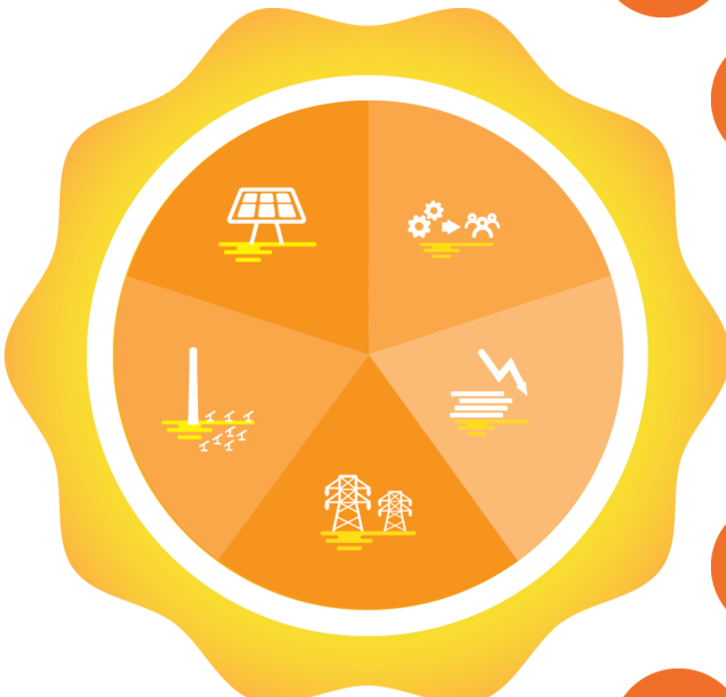


8,000
solar businesses
in the U.S.

$17.8 billion:
Value of the U.S. solar market
in 2014

50%
Solar systems costs are down
50% Since 2010

Progress Towards SunShot Goal



6¢/kWh

70% to the SunShot goal

Maintaining U.S. Leadership in PV R&D Innovation

Empowering Communities to Cut Red Tape, Streamline Processes

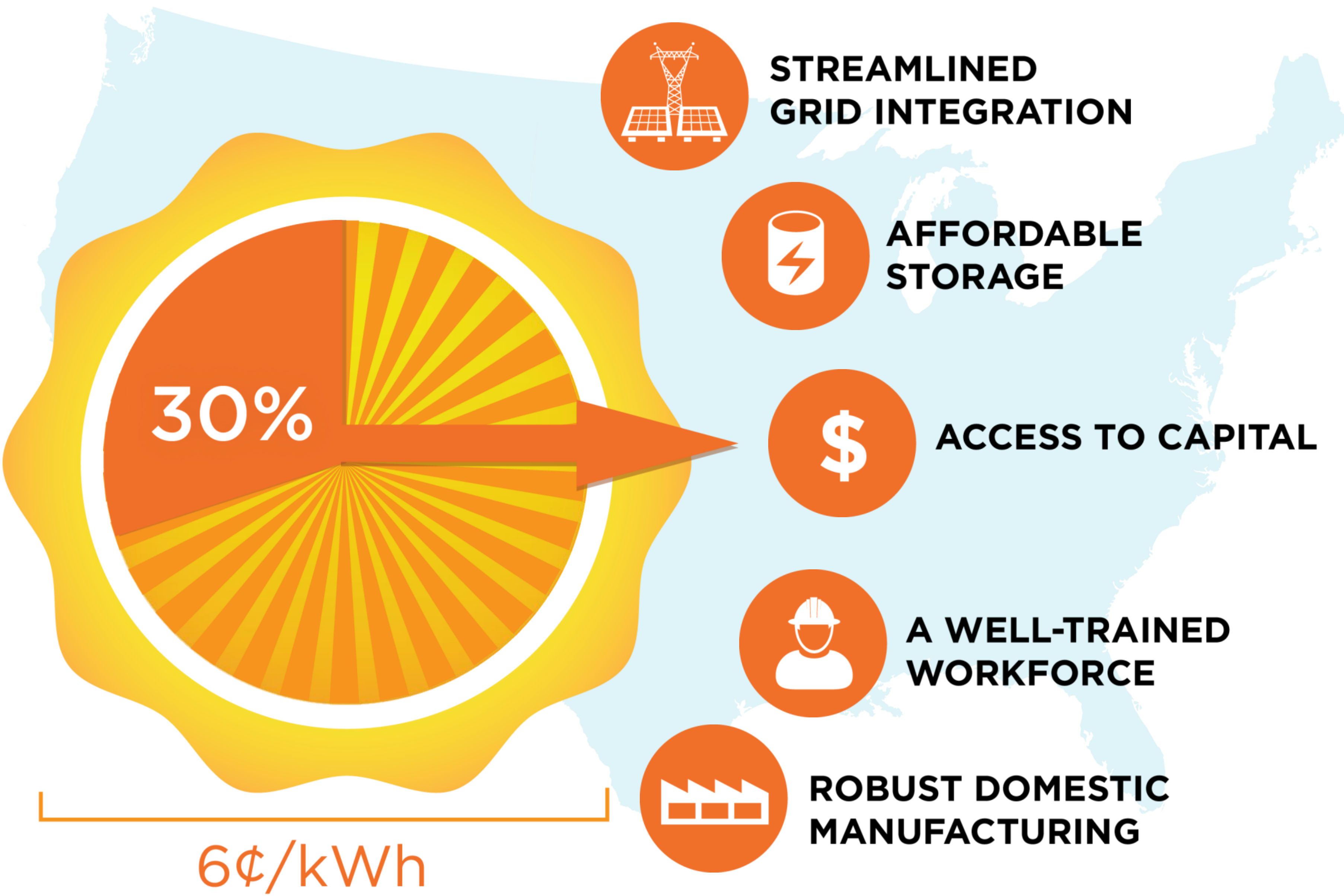
Building a Skilled Solar Workforce

Supporting Entrepreneurs and Innovators

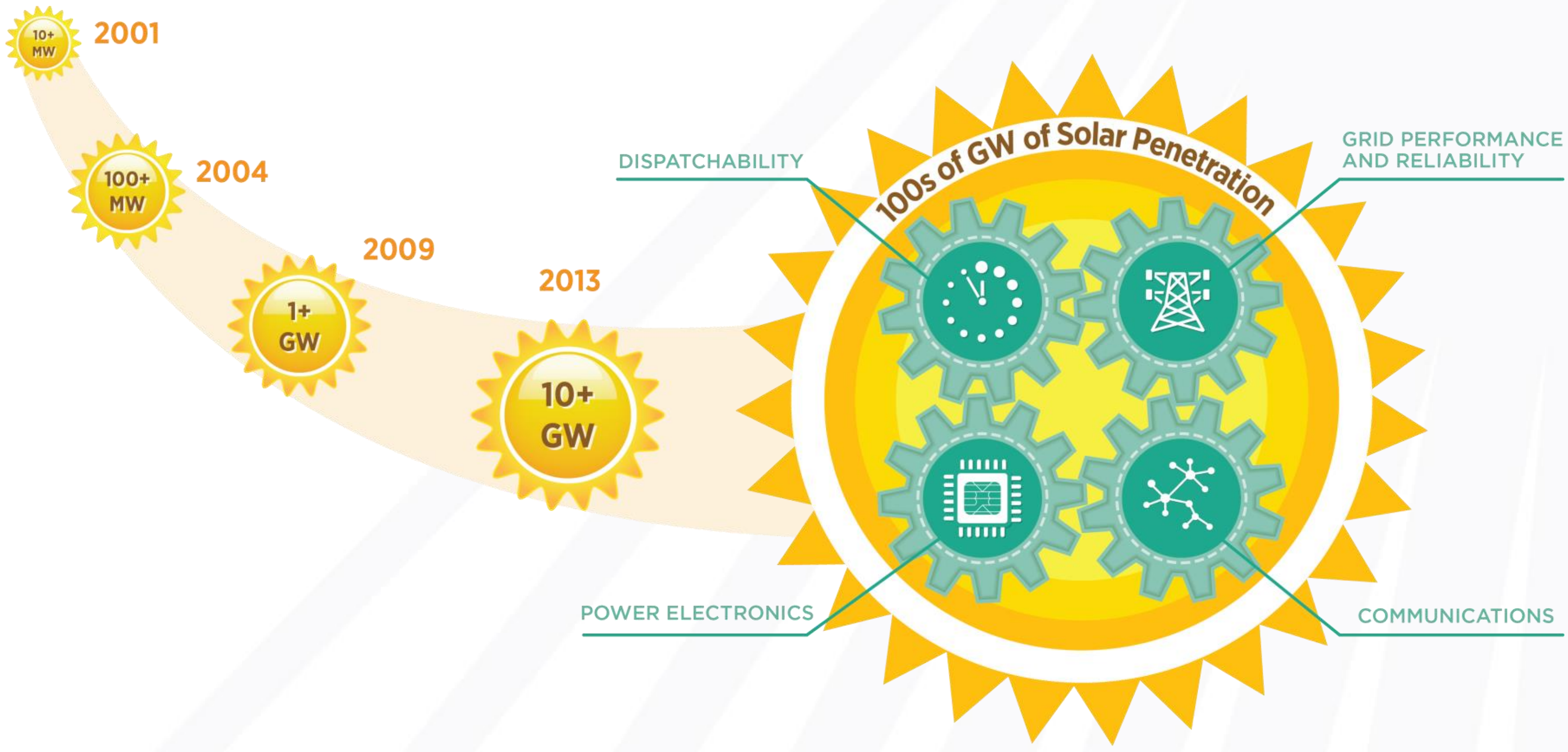
Training Veterans for the Clean Energy Economy

Supporting Domestic Manufacturing

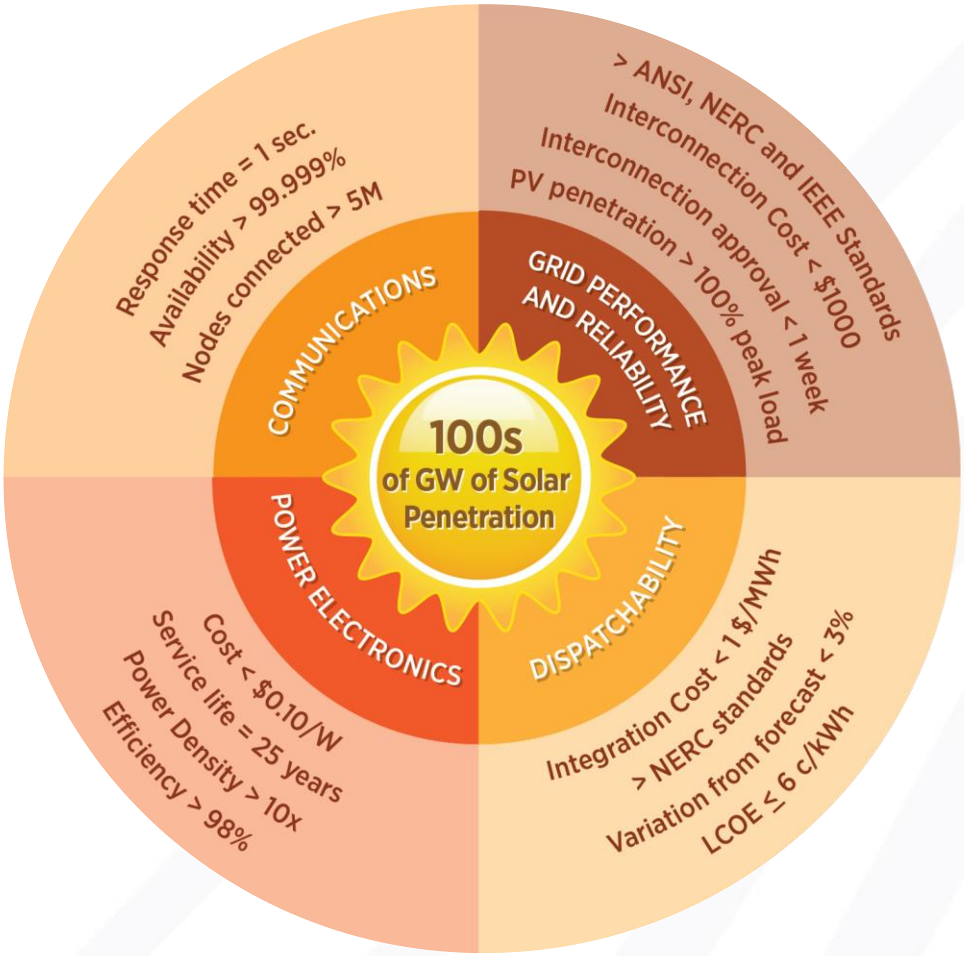
SUNSHOT GOAL: THE FINAL PUSH



The Systems Integration Vision

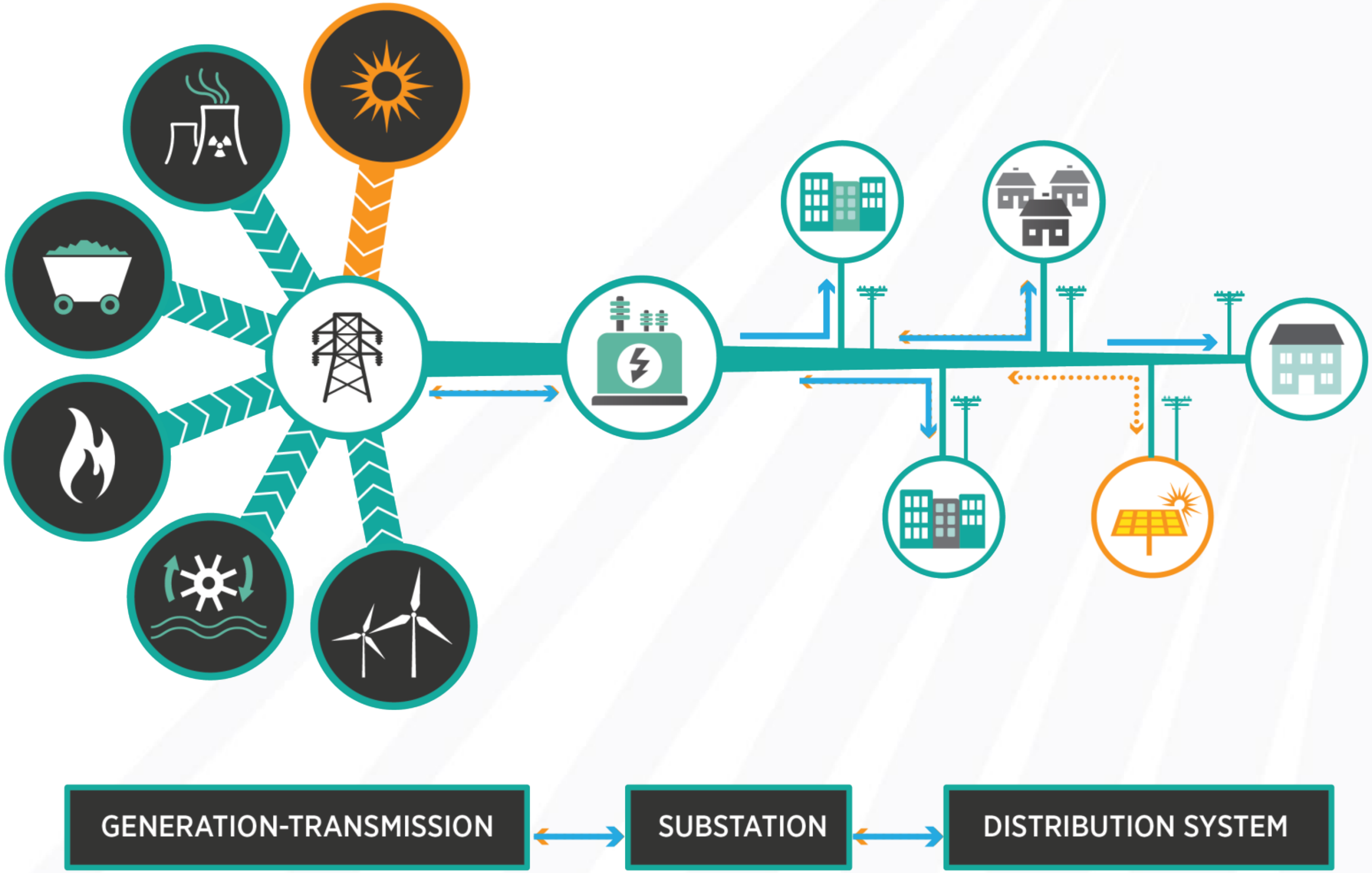


SunShot SI Funding Initiatives



- $59M SuNLaMP (2015)
- $15M SHINES (2014)
- $ 4M SUNRISE (2013)
- $ 1M PREDICTS (2013)
- $77M National Lab R&D (2012)
- $38M HiPen (2012)
- $25M Plug and Play (2012)
- $11M Solar Forecasting (2012)
- $56M BOS-X (2011)
- $30M SEGIS-AC (2011)

Grid Performance and Reliability



Addresses technical and regulatory challenges of integrating high penetration of solar generation at the transmission and distribution levels in a cost-effective manner, while ensuring safety and reliability of the electric grid

Grid Performance and Reliability: Key Metrics

1. High penetration of solar generation
   - PV penetration > 100% of peak load in a line segment as defined by FERC SGIP
2. Reduce interconnection approval time for solar projects
   - < 1 hr (residential); < 5 days (commercial and utility scale)
3. Reduce interconnection cost for solar projects (*excluding hardware mitigation costs*)
   - < $100 (residential); <$1,000 (commercial and utility scale)
4. Provide decision support, predictive analytics and economic analysis tools for utility planning and operation
   - Real-time (< 5 sec resolution) analysis, visualization, monitoring and mapping of “Big Data” sets from distribution feeder sensors, SCADA, GIS, CIS (Customer Information System), AMI, OMS (Outage Management System) and others
   - Optimal sensor placement software tools or apps to minimize cost of distribution sensors and maximize sensor data use for time series analysis
5. Scalability and Interoperability
   - Hardware and software tools must be scalable and dynamically adaptable to any level of PV penetration and must interface seamlessly with utility legacy systems
6. Maintain or Exceed present and future grid performance standard
   - > ANSI, IEEE, NERC standards

NREL/SCE Hi-Pen PV Integration Project

5 MW Fixed-Tilt Ground-Mount System near Porterville, CA

2 MW Warehouse Roof Mounted PV System near Fontana, CA

- Impetus – in 2009 SCE received approval to install 500 MW of distribution-connected PV in their service territory
- Focus – developing new “rules of thumb” for utility planning engineers for interconnecting large (1-5MW) PV systems on medium voltage (MV) distribution circuits and developing methods to reduce the PV impacts on these systems
- Goal – easing the interconnection concerns of utilities faced with utility-scale distribution-connected PV systems, enabling utility engineers to correctly assess a PV systems potential circuit impacts, and demonstrating that there are current methods for mitigating the impacts of high-penetration PV that can be implemented in the near-term for low cost

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QUANTA TECHNOLOGY

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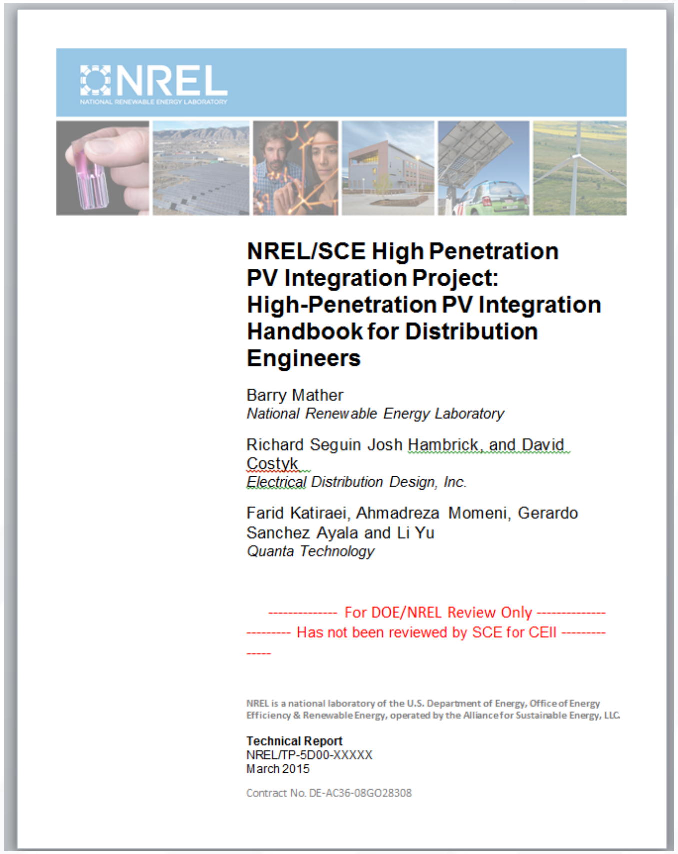
NREL/SCE Hi-Pen PV Integration Project

Development of a hi-pen PV integration handbook for distribution engineers:

- Condensing the experience gained and research results of the entire project into a handbook for use by distribution engineers facing hi-pen integration challenges in their service territories
- Research expanded to include utility practices and operations beyond just SCE's current practices and operations (i.e. using capacitors as their sole method of voltage regulation)
- Reviewed by practicing distribution engineer experts working on PV interconnection


NREL
NATIONAL RENEWABLE ENERGY LABORATORY

NREL/SCE High Penetration PV Integration Project: High-Penetration PV Integration Handbook for Distribution Engineers

Barry Mather
National Renewable Energy Laboratory

Richard Seguin Josh Hambrick, and David Costyk
Electrical Distribution Design, Inc.

Farid Katiraei, Ahmadreza Momeni, Gerardo Sanchez Ayala and Li Yu
Quanta Technology

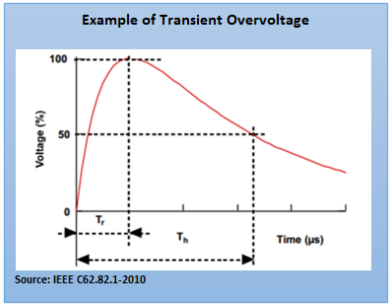
-------------- For DOE/NREL Review Only --------------
--------- Has not been reviewed by SCE for CEII ---------

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, operated by the Alliance for Sustainable Energy, LLC

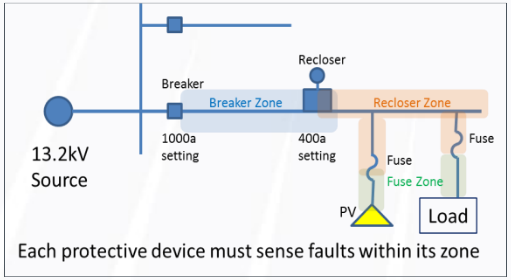
Technical Report
NREL/TP-5D00-XXXXX
March 2015

Contract No. DE-AC36-08GO28308

Handbook is approachable by practicing engineers



Transient OV example



PV protection impacts examples

Structure	Device Number	Size (kVAR)	Control	Start Schedule	End Schedule	High voltage	Low Voltage
6046T	0013914	600	Time-Bias Voltage	7:04 AM	9:04 PM	126	121
894563E	0013089	600	Time-Bias Voltage	12:00 AM	12:00 AM	125	120
1351925E	0040409	600	Voltage	6:04 AM	10:04 PM	126	121
755658E	0013903	600	Time-Bias Voltage	9:04 AM	7:04 PM	126	121

Typical Cap Setting

- high voltage over-ride 124V for 60 seconds
- low voltage over-ride 115V for 60 seconds
- high voltage during schedule: 126V
- low voltage during schedule: 122V
- high voltage during non-schedule: 122V
- low voltage during non-schedule: 118V
- high / low voltage threshold: 3 min
- maximum operations: 10
- emergency high voltage over-ride: 128V for 5 seconds

Capacitor Location	Flicker on 120V Base
600kVAr Cap 13089	1.7 Volts
600kVAr Cap 13903	0.7 Volts
600kVAr Cap 13914	1.3 Volts
600kVAr Cap 40409	2.8 Volts

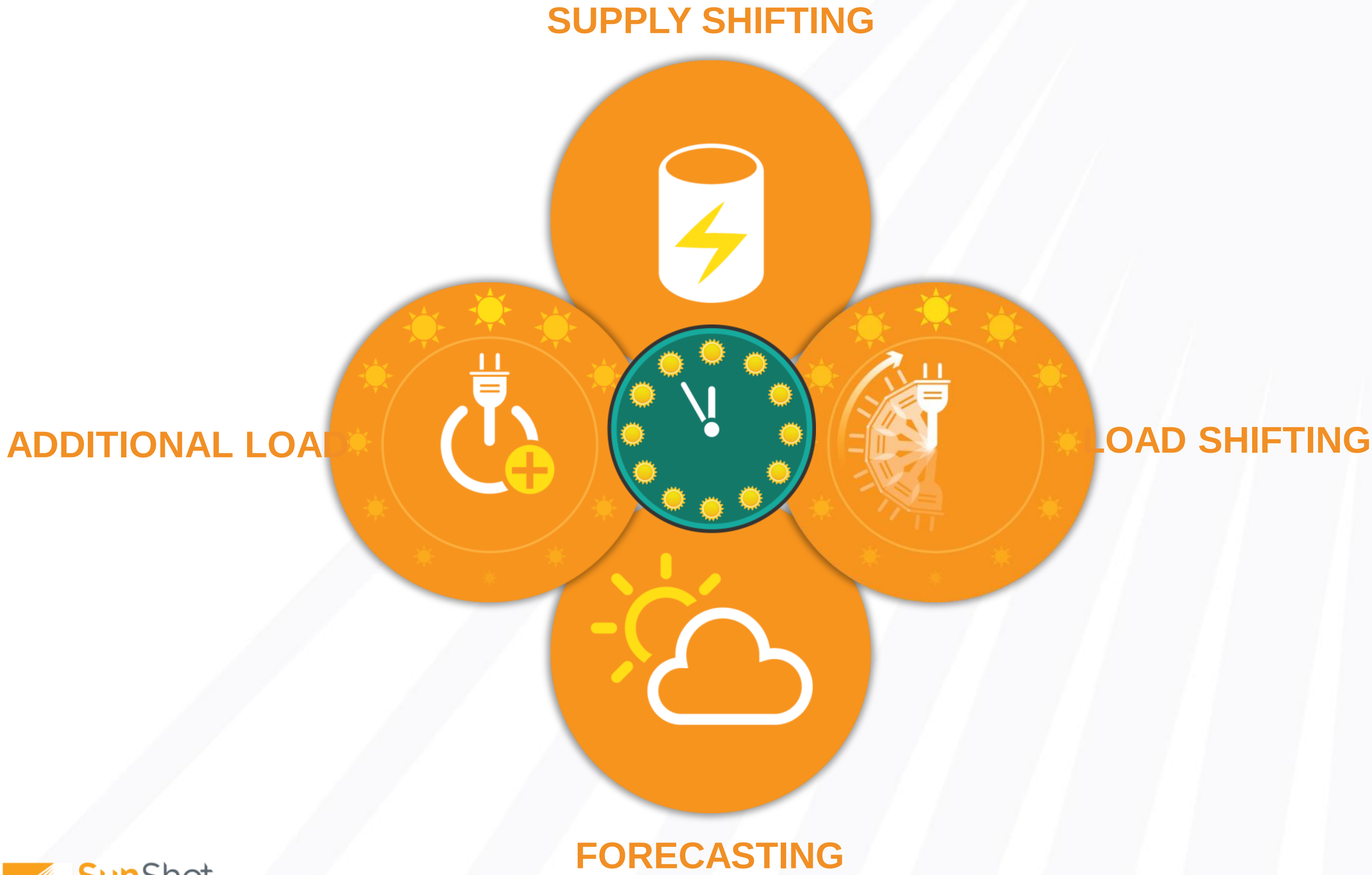
Example PV impact assessment

Dispatchability

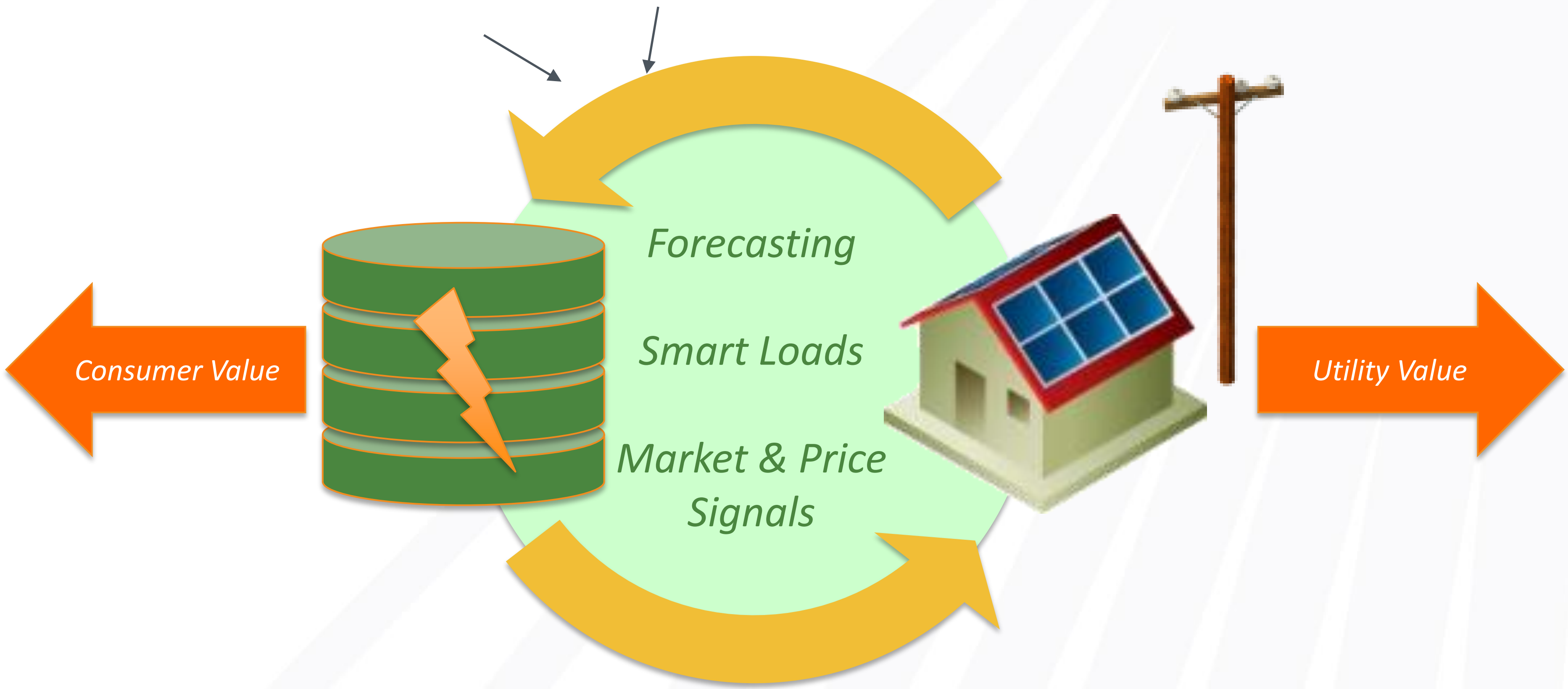
Dispatchability: Key Metrics

1. Reduce integration cost of solar plants (both PV and CSP)
    - Integration cost < $1/MWh
2. Exceed current and future grid performance standards
    - > NERC standards
3. Accurately predict power production from solar plants
    - < 3% variation from forecasted power generation from solar plants, at all timescales
4. Achieve dispatchability of solar plants that meet or exceed utilities/ISO dispatch rules for conventional generation, while maintaining SunShot levelized cost of electricity (LCOE) target
    - > Utilities/ISO dispatch rules
    - LCOE < 6 ¢/kWh at the utility scale, without subsidy, by the year 2020

Dispatchability Solution Set



SHINES Vision



- $15M FOA (50% cost share)

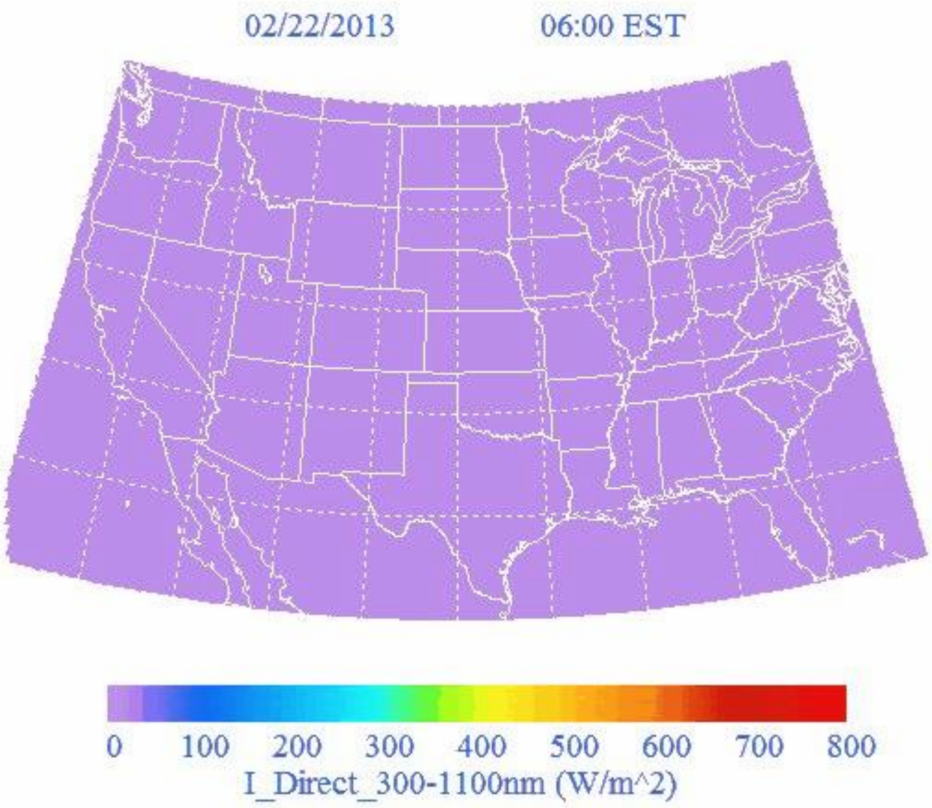

PIENSE
THINK
ΣΚΕΨΟΥ
DENKE
सोचिए
PENSER
$300,000
$1,000,000
$200,000
Who is Stoker?
(I FOR ONE WELCOME OUR NEW COMPUTER OVERLORDS)
$ 1,000
Who is Bram Stoker?
$ 17,973
WHO IS BRAM STOKER?
$5600
JEOPARDY!

Watt-Sun:
A multi-model, machine learning Renewable Energy Forecasting Technology

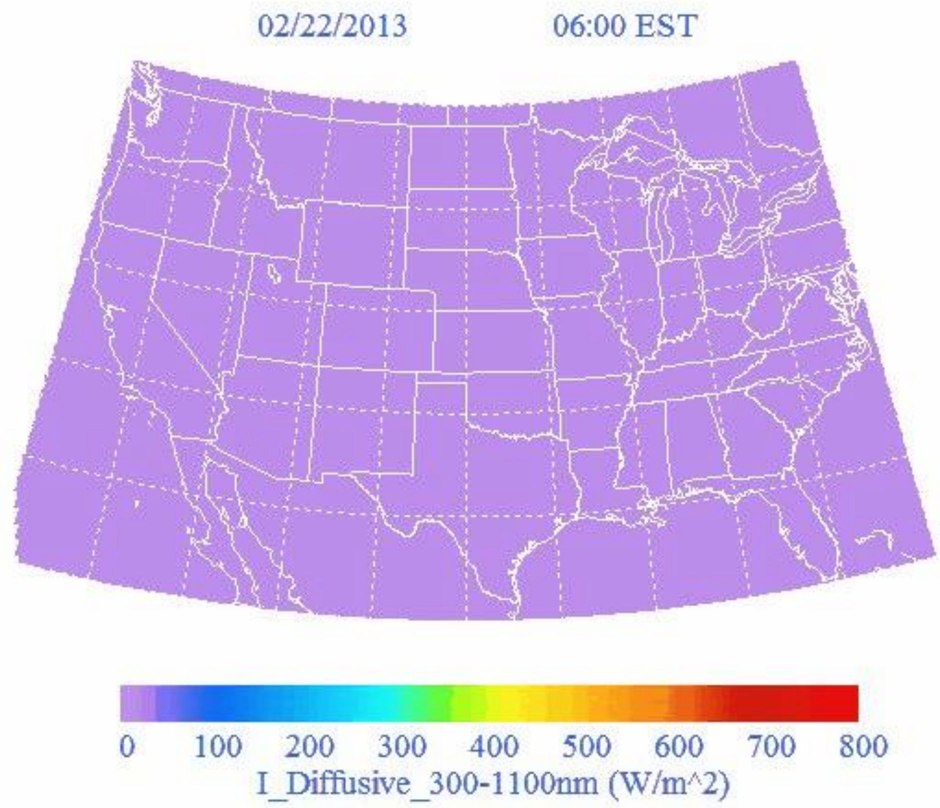
© 2014 IBM Corporation

Example: Solar Irradiance Forecasting

Direct Irradiance



Diffusive Irradiance

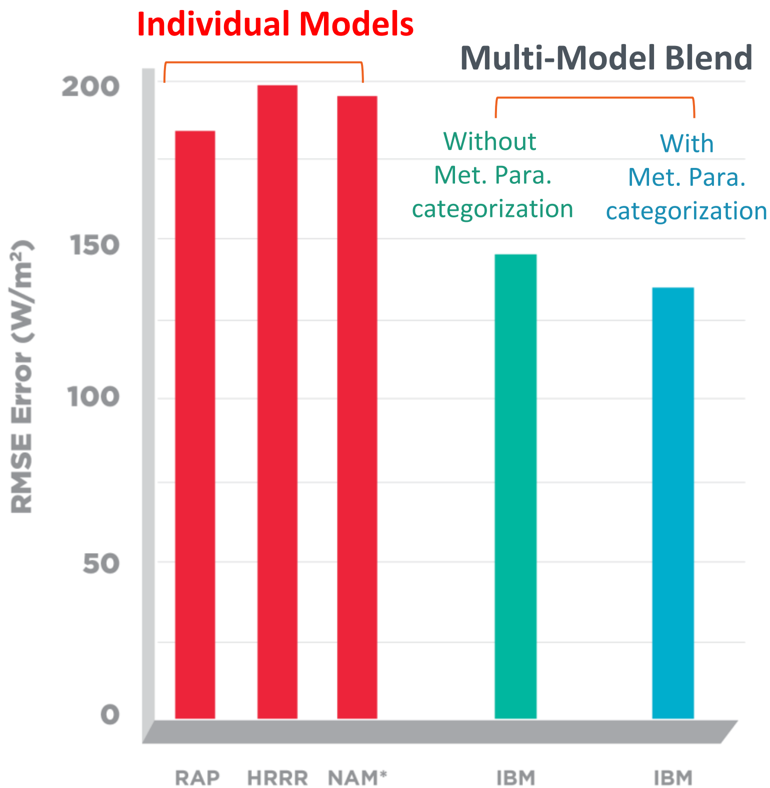


Currently operational and optimized forecasts for entire continental US are available

Machine Learning Results

Solar Irradiance Forecast

Averaged for 14 NOAA sites



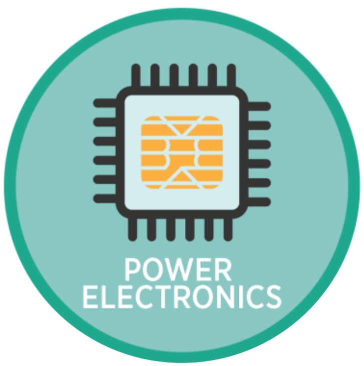
PV Power Forecast

Smyrna TN 1MW PV plant

ML / Model Blending approach has lead **so far to significant % improvements** over traditional single model approaches for both irradiance and PV power forecast skill.

Day Ahead Forecast Validation Period 05/01/13 to 09/30/13. *RAP, HRRR, NAM are three state-of-art NOAA high-resolution weather models, ** RMSE normalized by installed capacity

Power Electronics



Critical components in PV systems and the larger electric grid to convert electricity from one form to another and deliver it from generation to end consumption.

- **2005:** ~30% of electricity flow through PE devices
- **2030:** est. 80% of electricity flow through PE devices.*

Power electronics are intelligent devices that

- Maximize power output from PV arrays,
- Interface between PV systems and the transmission and distribution grid,
- Are capable of self-diagnostics, automated control, and fault protection to ensure overall system safety, reliability, and controllability
- Can be integrated with smart weather stations, energy storage, and customer load to provide a wide range of services.

** L.M. Tolbert, et al., "Power Electronics for Distributed Energy Systems and Transmission and Distribution Applications: Assessing the Technical Needs for Utility Applications," ORNL Technical Report, 2005.*

Power Electronics: Key Metrics

SunShot solutions will leverage transformative power electronics technologies including solid state device technologies, high power density electronics, nanomaterials/technologies, wide band gap semiconductors, advanced magnetics, thin film capacitors, and advanced system design and packaging to enhance solar power conversion and energy flow in the transmission/distribution grid and in customer premises.

Power Electronics Ratings: 250 W (microinverters) – MW level (utility scale)

Conversion Efficiency > 98%

ratio of the usable output power (AC or DC) versus available input power from the PV panels.

Service Life > 25 years

useful life of the power electronic subsystems to support the required plant availability under normal operation and maintenance.

Power Density > 10x

ratio of rated output power versus device volume and weight.

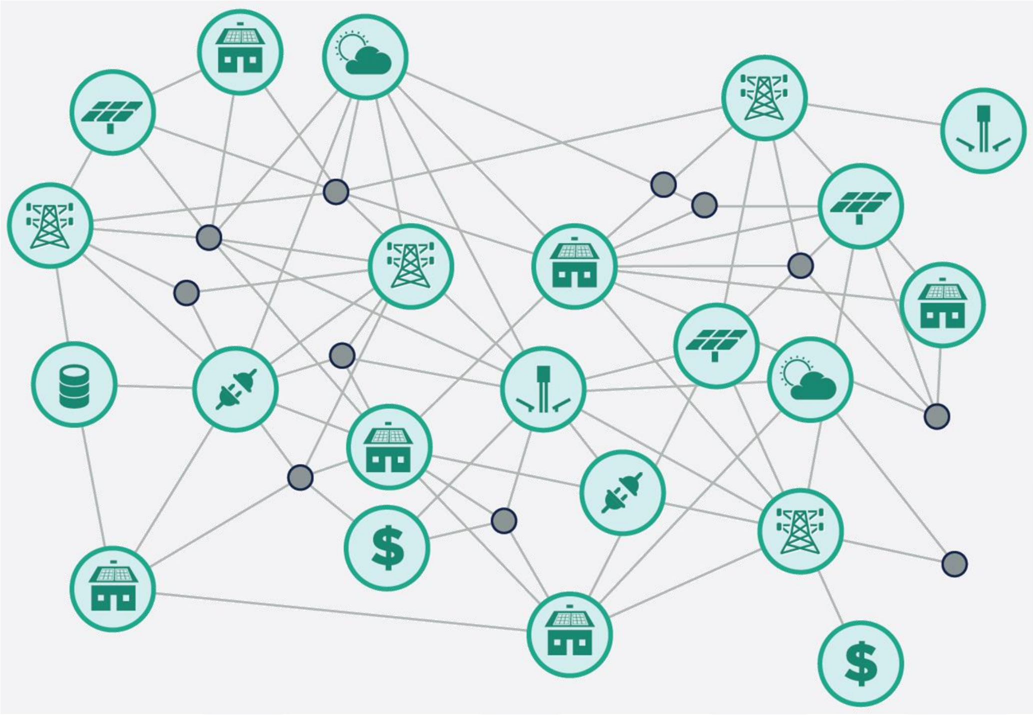
System Cost < $0.10/W

lifetime cost of the power electronic device, including initial capital cost and the operation and maintenance (O&M) cost over the life of service.

Grid-Support Functions — Compliant with Grid Codes

smart inverter functions such as volt/var, volt/watt, frequency/watt, voltage ride-through, power factor control, reactive power support, ramp rate control, etc., activated either autonomously through default settings or remotely through utility SCADA commands.

Communications



To effectively inform grid operations, the utility system requires visibility and control of solar generators at several spatial and temporal scales.

The transformation of the electric grid from a centralized and hierarchical network architecture to a more distributed one – with ever increasing number of small and/or variable generators scattered throughout the grid – adds significant system complexity and technical challenges in communication.

SunShot solutions will leverage existing communication technologies and develop new communication and control architectures to collect, store, visualize, and analyze real time operation data which is growing exponentially. *Example technologies include fiber optics, digital cable, DSL, 3G/4G cellular wireless, WiFi, WiMAX, RF radio, satellite, power line communication (PLC), Zigbee, wireless mesh, etc.*

Communications: Key Metrics

Scalability up to 5 Million Nodes

ability to scale the communication network in the number of connected nodes, bandwidth, latency, and coverage distance in order to meet the needs of various applications.

Availability > 99.999%

defined as the probability that the communication network will perform without a failure for a stated period of time. Includes the performance of the physical network as well as the accuracy of the messages being sent and received.

Response time < 1 sec

delay between the moment a message/command is sent from the source node and the moment at which that information is received and acted upon at the destination node.

Interoperability – Compliance to Open Standards

defined as the capability of two or more networks, systems, devices, applications, or components to exchange and readily use information—securely, effectively, and with little or no inconvenience to the user. ("NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 2.0,", Smart Grid Interoperability Panel (SGIP), NIST, 2012)

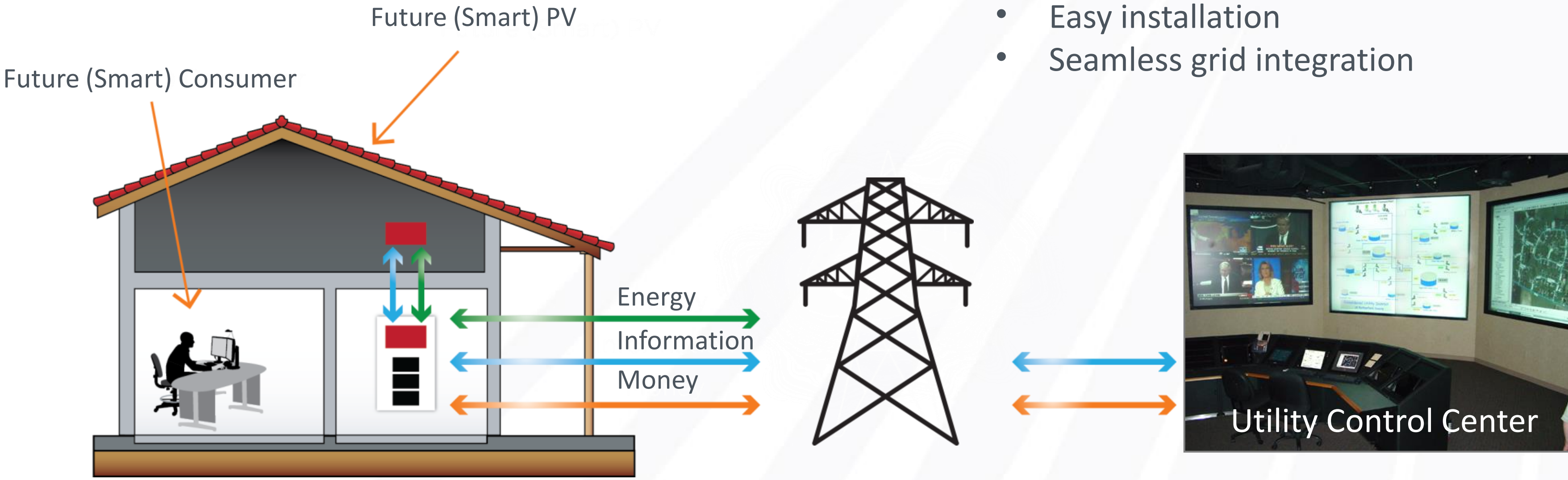
Communications cost to support LCOE < 6 c/kWh

defined as the life-cycle cost of building, operating, and maintaining the communication network and end devices. Includes initial capital costs for equipment and infrastructure build-up and the recurring costs for operation and maintenance.

Plug-and-Play Vision

Vision: PV as an Appliance

- No permitting required
- Easy installation
- Seamless grid integration



Future (Smart) Home
• Smart outlet • Smart circuit • Smart breaker panel • Smart appliances • Home area network (HAN)

Future (Smart) Grid
• Distributed generation • Two-way power flow • Communication and control • Rich energy information and transactions • Microgrid

Future (Smart) City
• Integrated grid and city planning

Forbes

Peter Kelly-Detwiler, Contributor
I cover the forces and innovations that shape our energy future.

ENERGY | 8/07/2013 @ 8:57AM | 4,793 views

Plug-And-Play Residential Solar in three years ? Fraunhofer USA And Partners Are Working To Make This A Reality

Fraunhofer CSE demonstrates Plug and Play PV System installation and commissioning in just 75 minutes at the Massachusetts Clean Energy Center's Wind Technology Testing Center, November 19, 2014

Photo Credit: Fraunhofer CSE

GEARED regional centers for technology engagement

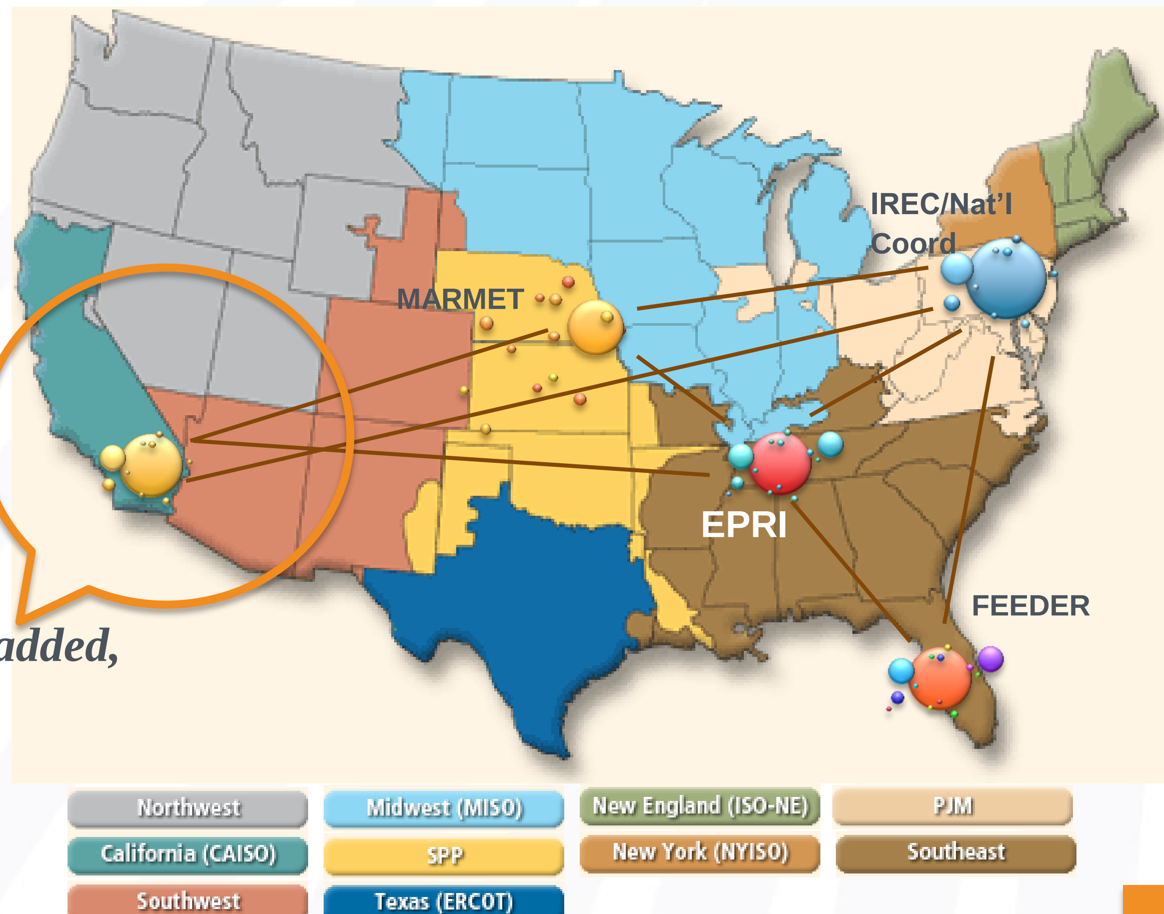
GEARED

- Each Consortia brings together: **utilities**, **grid operators, university faculty, manufacturers and analysts**
- Consortia focuses students on **Distributed power** and cyber-physical systems analysis
- Consortia offer **training** programs: **internships** & coops, continuing education, **research exchange**, **executive training**, support for IP development

42 Universities
4 National Labs

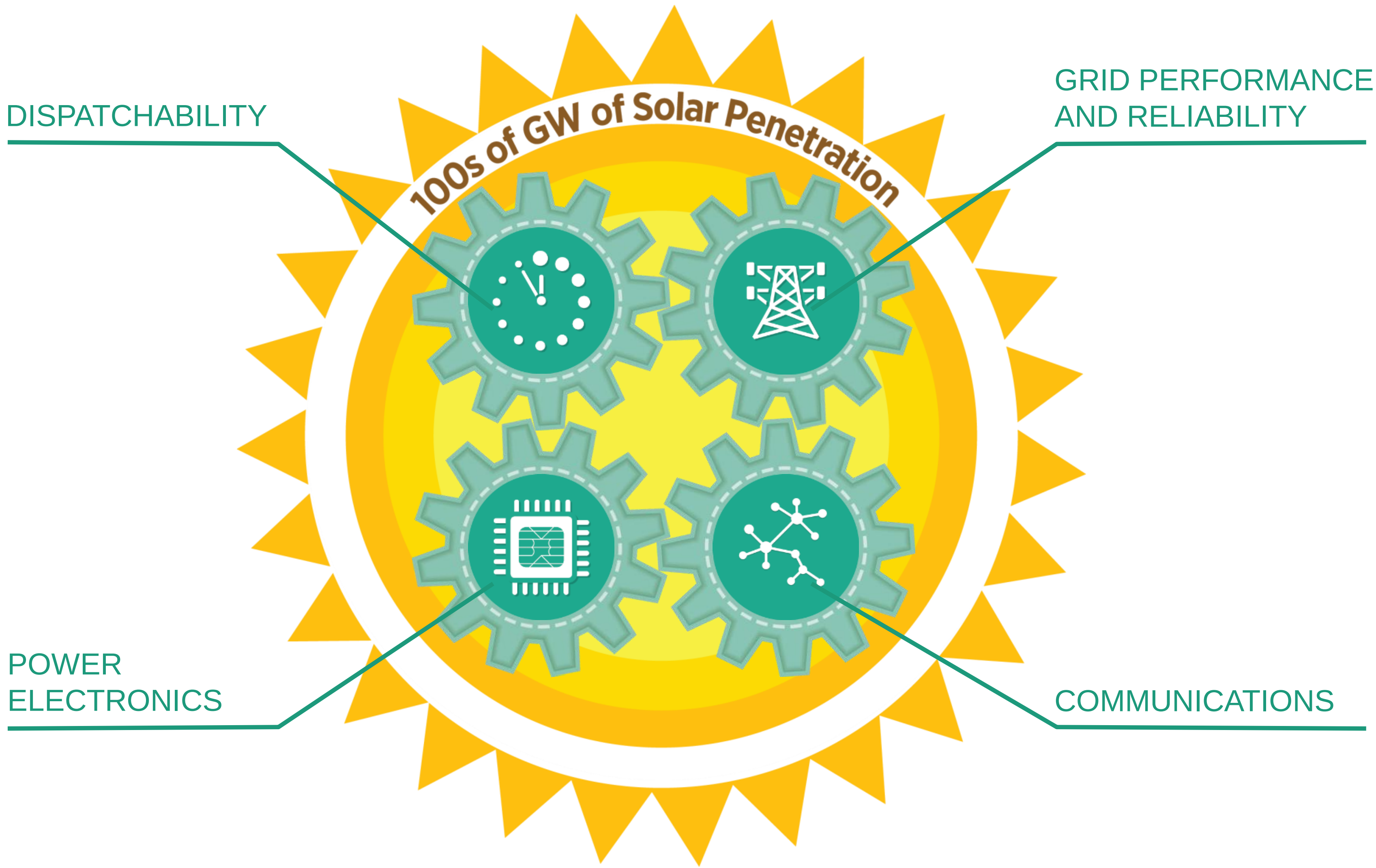
49 Utilities
12 Solar Companies

~2,800 Students



To be added, 2016

SunShot:
- **5 year program**
- **National Coordination**


100s of GW of Solar Penetration
DISPATCHABILITY
GRID PERFORMANCE AND RELIABILITY
POWER ELECTRONICS
COMMUNICATIONS